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Arlington, VA

Balancing Capacity vs. Capability

Laser Weapons for Naval Applications

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Report Documentation Page

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Outline

- Background
- Laser candidates
  - Free electron lasers
  - Solid state lasers
- Additional capabilities
  - Power beaming

Laser Lethality

- Thermally ablating 1/4 pound of target material requires ~ 1.3 MJ of laser energy

- 1 MJ is equivalent to ~ 1/2 pound of explosive

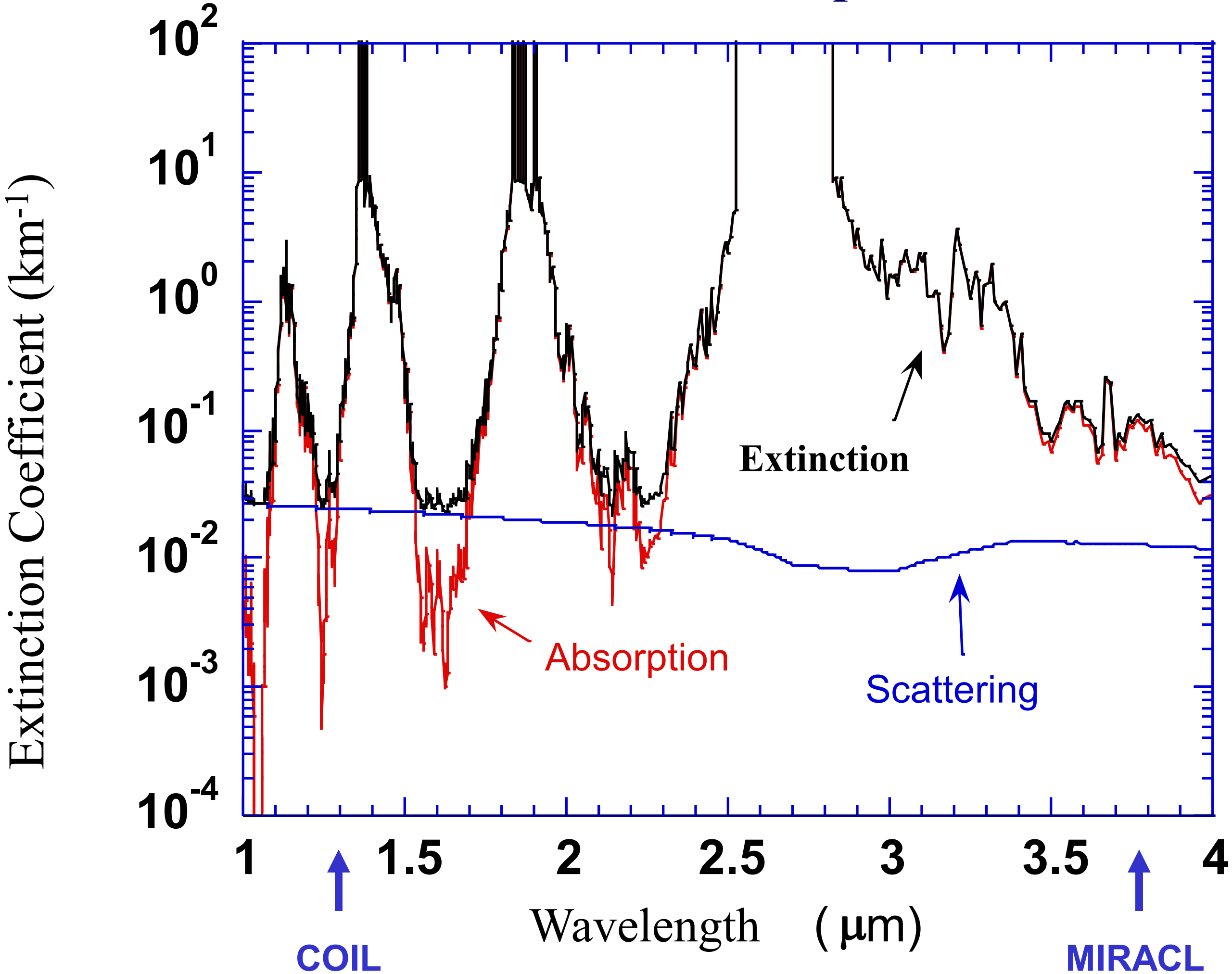
- 100 kW of <u>absorbed</u> laser power for 2 sec ablates ~ 20 grams (~ 8 pennies)

- For an engagement time of 5 sec the required laser power is > 250kW

Capabilities of Laser Weapons

- Agile speed of light delivery (instantaneous)
- All electric energy source (deep magazines)
- Long range targeting
- Multi-targeting
- Compatible with all electric ships

Extinction Coefficient vs Wavelength
Maritime Atmosphere



Maritime Windows

~ 1µm
~ 1.25 µm
~ 1.6 µm
~ 2.1-2.3 µm

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Laser Systems for Naval Applications

- Free Electron Lasers

  - Jefferson Lab.   P > 14 kW, $\lambda \sim 1.6\ \mu m$

- Solid State Lasers

  - IPG fiber lasers, 10 kW/fiber

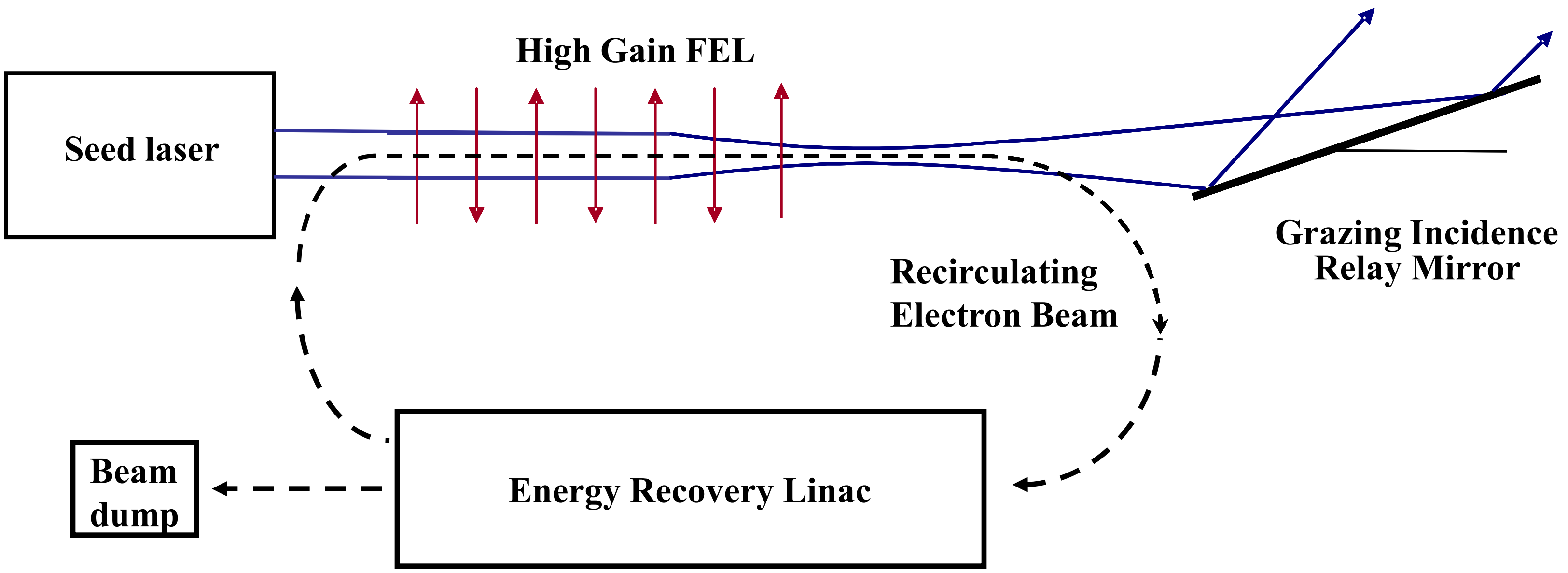
  - Northrop Grumman JHPSSL

    100 kW (2011), 7 tiles
    $\lambda = 1.06\ \mu m$ (N_d:YAG)

Free Electron Lasers

- High average power capability
- Output wavelength is tunable
  (can operate in atmospheric window)
- Wall-plug efficiency ~ 10% (potentially)
- Dimension ~ 4m x 4m x 30m, for 100kW to ~ 1MW
- Ship power requirements > 10 MW
  (engagement time ~ 10s of minutes)

High-Gain, High Efficiency Free Electron Laser



- Electrons undulate in wiggler field and bunch at optical wavelength
- Optical radiation is amplified

Example: $\lambda_w = 3\,\text{cm}\,, \quad E_b = 80\,\text{MeV} \qquad \lambda \approx 1\ \mu m$

Goal: $\langle P \rangle \sim 1\,\text{MW} \qquad \lambda = 1\mu m,\ 1.6\mu m,\ 2.3\mu m$

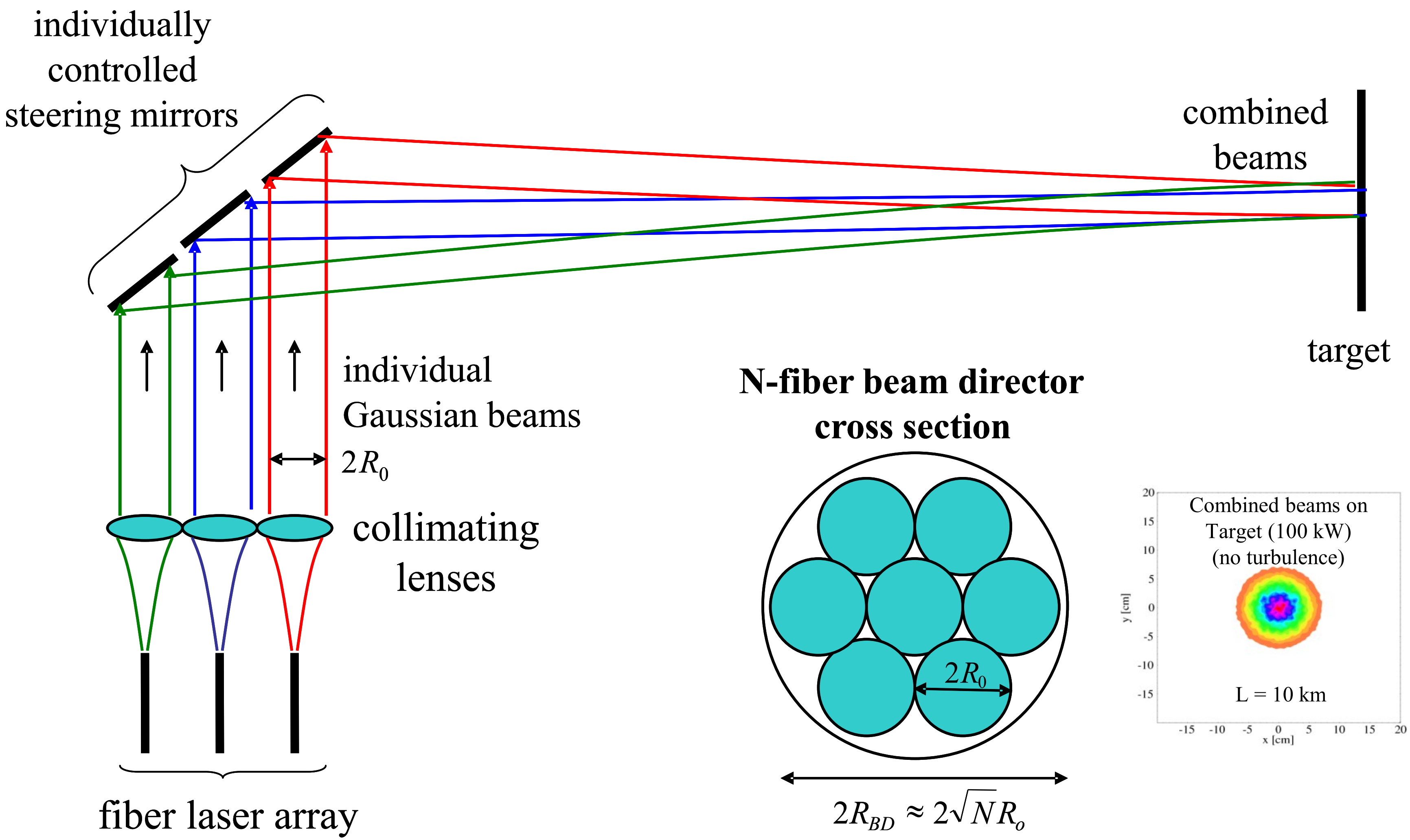
Fiber Lasers

- Compact
- High-Power $$P_{fiber} = \begin{cases} 8\,kW, & \text{commercially available} \\ 10\,kW, & \text{state-of-the-art} \end{cases}$$
- Robust
- High Wall – Plug Efficiency (> 30 %)
- High Optical Quality

Fiber Laser

(1 kW, 1.6 kW, 1.6 kW and 2 kW)

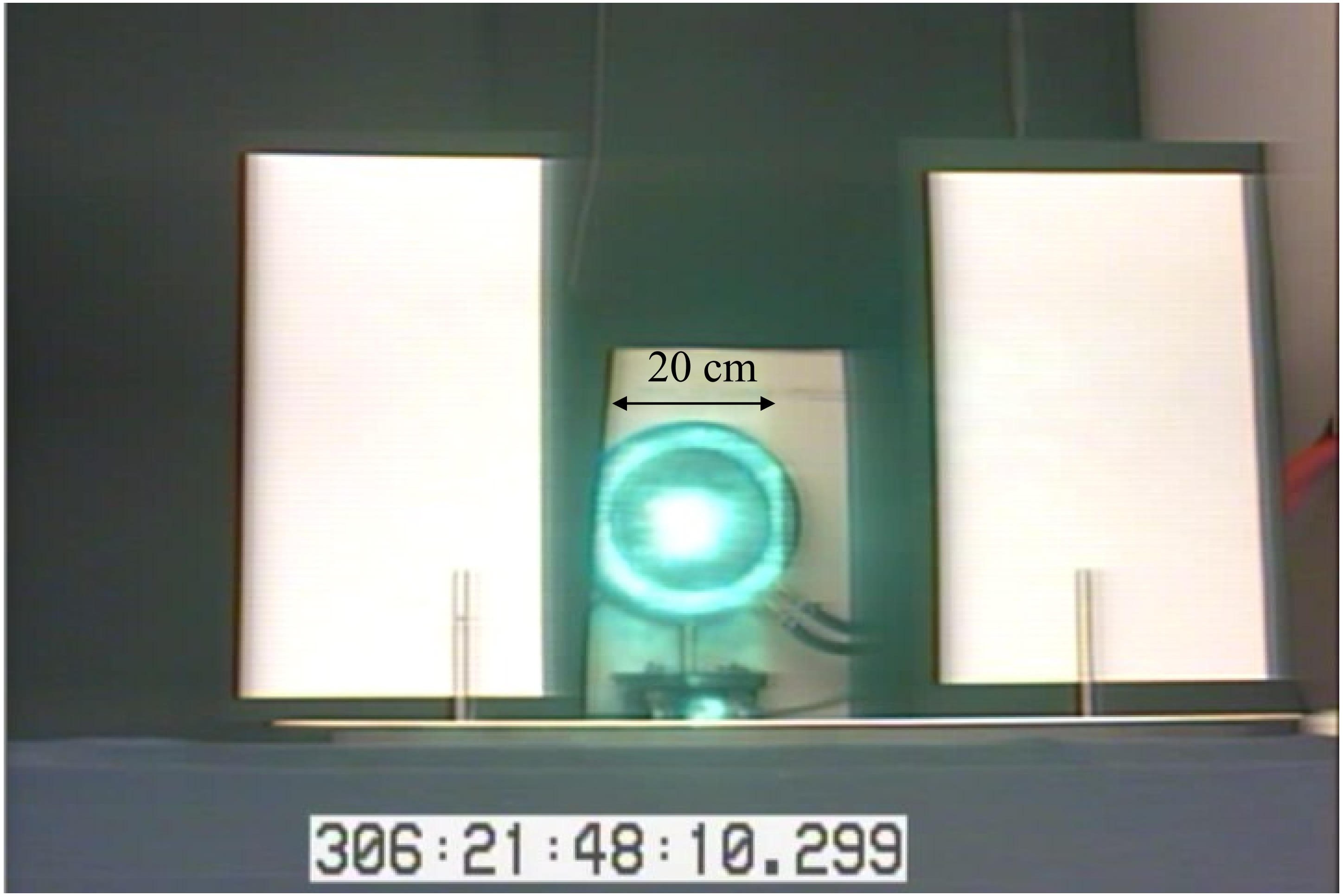
Incoherent Combining of Fiber Lasers



- **NRL** Memorandum Report -6790-06-8963; also **JDE 2,** 273 (2007)
- U.S. Patent # 7,970,040 B1 (June, 2011)
- **IEEE Journal of Quantum Electronics, 45,** No. 2 (2009)

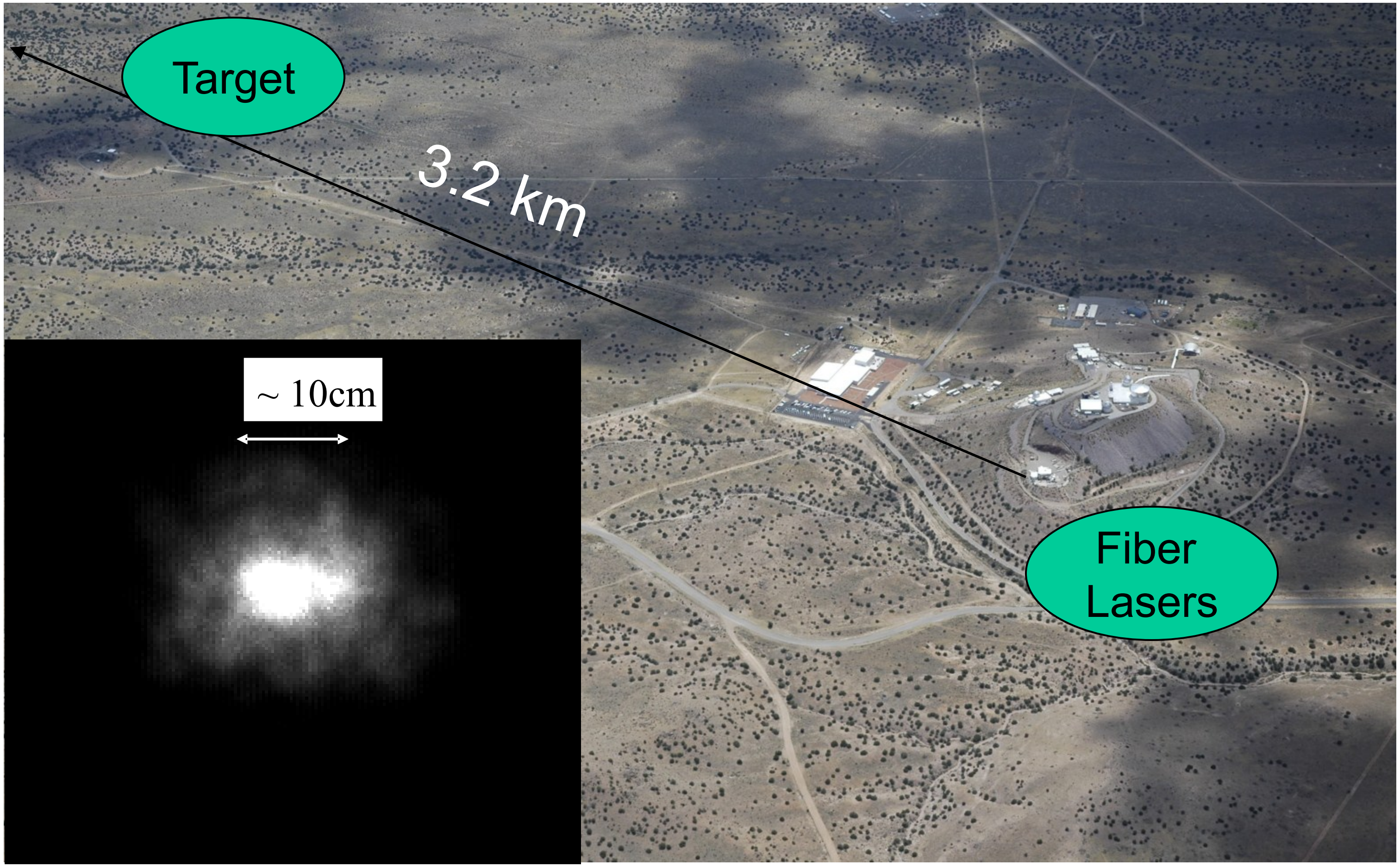
Four Incoherently Combined Fiber Lasers (NRL), 1.2 km Range

3 kW transmitted, 2.8 kW on target , 11/02/07



Starfire Optical Range (NRL) Propagation Range 3.2 km

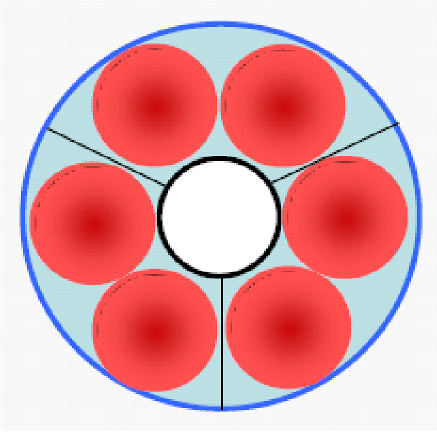
Incoherently combined fiber lasers, ~ 5 kW, cw, $M^2 \sim 1$



Navy Laser Weapon System (LaWS)

- Based on the successful results of the NRL fiber laser program, the Laser Weapon System (LaWS) program (classified) was started in 2008 by NAVSEA, PMS 405

Power per fiber ~ 5 kW



- Successfully tracked, engaged, and destroyed a UAV while in flight (May 24, 2010)

500 kW Fiber Laser Weapon System

- Laser power, CW: $P = 500\,\text{kW}$
- # of Fiber lasers : $N = 63 \quad (P_{\text{fiber}} = 8\,\text{kW}$, incoherently combined)
- Wall – plug efficiency $\sim 30\ \%$
- Beam director: $R_{BD} = \sqrt{N}\,R_o \approx 50\,\text{cm}$
- Volume of optics $\approx 8\,\text{m}^3$
- Weight of optics $\approx 10{,}000\,\text{lbs.}$

excluding power supply and cooling

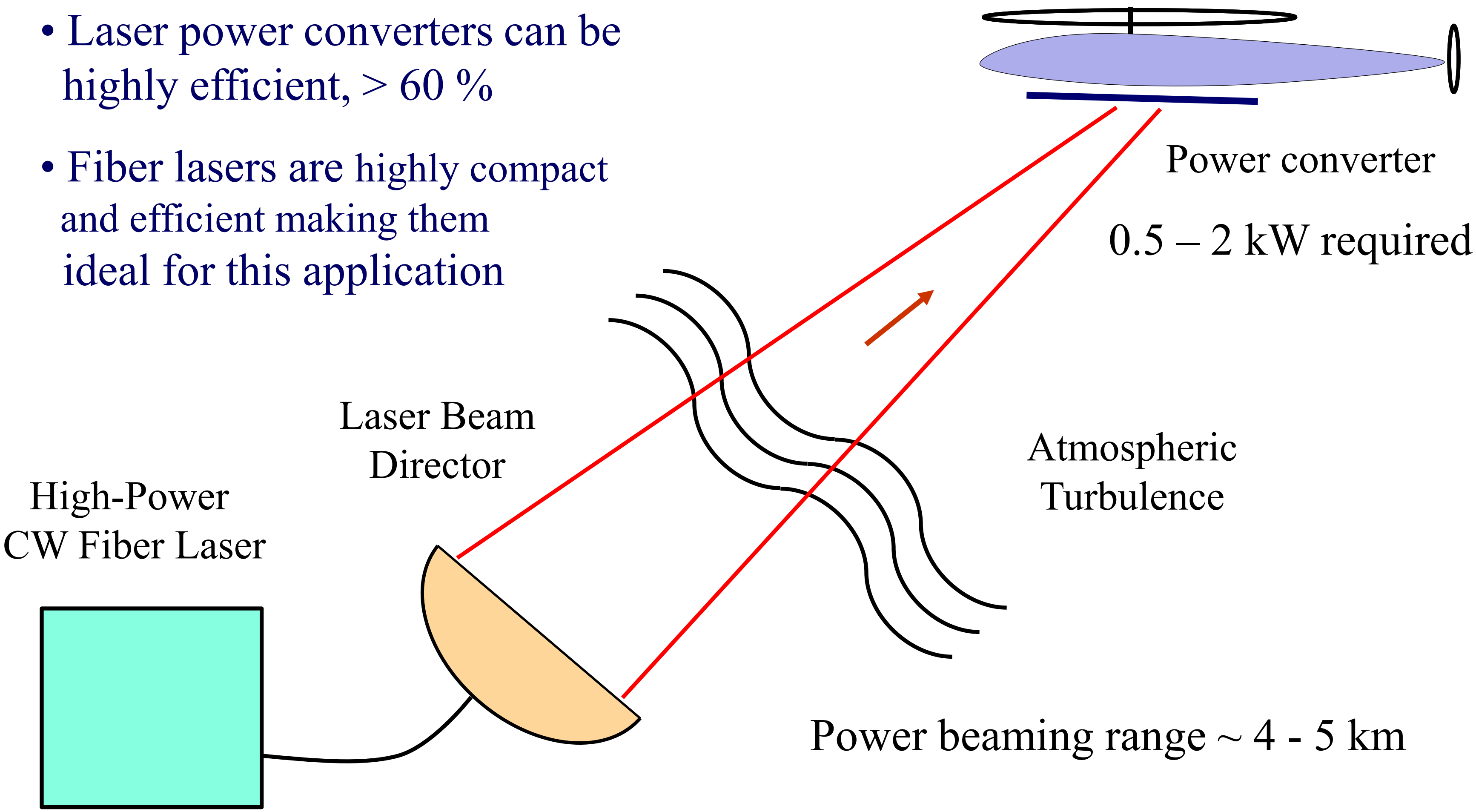
- Water cooling ~ 1,000 gallons/min.

Solid State Slab Laser

- Joint High Power Solid State Lasers (JHPSSL)
- Wavelength, 1.06 μm
- Power achieved 105 kW (2009) - Northrop Grumman
- Wall-plug efficiency, 20%
- Modular design
- Compact

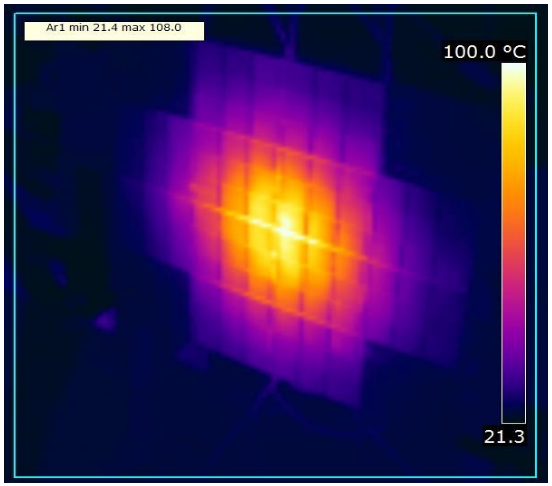
Laser Power Beaming
New Operational Capabilities for the Navy/DoD

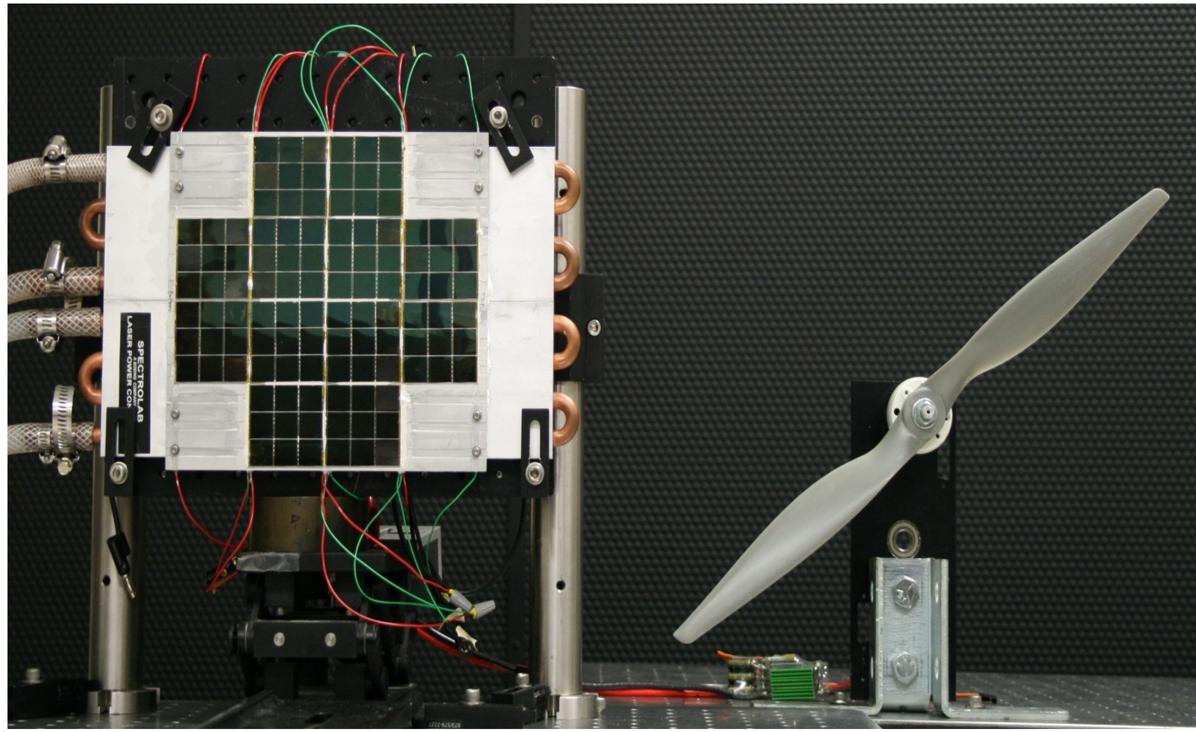
- Multiple kilowatts over multiple kilometers
- Laser power converters can be highly efficient, > 60 %
- Fiber lasers are highly compact and efficient making them ideal for this application



Laboratory Demonstration of Laser Power Beaming using Fiber Lasers

Semiconducting Convertor: InGaAs
Spectrolab





- Efficiency ~ 42%
- 9 chips in series yields ~ 6 V, 8 A
- Total power ~12 x 48 W = 576 W

Challenges

- Laser propagation in a maritime environment
  - turbulence
  - aerosols
  - thermal blooming
- Adaptive optics in deep turbulence
- Scalability to MW power levels
- Thermal management

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